THE VALUE TO PHYSIOLOGY

OF

ANTHROPOMETRIC TESTS AND MEASUREMENTS

IN THE FORM OF STATISTICS AND THEIR IMPORTANCE TO EDUCATION.

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THE VALUE TO PHYSIOLOGY OF ANTHROPOMETRIC TESTS AND MEASUREMENTS IN THE FORM OF STATISTICS AND THEIR IMPORTANCE TO EDUCATION.[1]

H. G. Beyer.

The great value of statistical records to the physiologist, as a means of studying certain physiological events, is, I believe, generally recognized. From the point of view which interests us most, these refer principally to changes in growth and development as they follow a certain definite chronological order. Thus, for example, if we were in the possession of a complete set of statistical records, taken in the order in which they occur or succeed each other, of the developmental stages of a number of human beings and their component organs, from the moment of their conception to the time of their death, who can doubt that such records would serve to contribute very largely also to the physiological history of the growth and development of an average human life ?

Up to the present time, however, we have but a few scraps of such a history. Imperfectly known as are these physiological events, we have long since attempted to promote and further them by a process known as training or education, here used in the broadest sense. In the course of time we have found out that the exercise of the normal function of any organ or tissue, besides giving us a measurable amount of work, will exert a reflex influence upon the structure, growth, and working capacity of that organ or tissue. The results of experiments in this direction have invariably shown that these assumptions were justified under certain well-defined conditions and circumstances. In the living animal body, under normal conditions and at rest, we find a condition of tissue-equilibrium.

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[1] Read in Section on Anthropometry at the meeting of the American Association for the Advancement of Physical Education, Fayerweather Hall, Columbia University, New York, April 19, 1901.

Tissue-equilibrium exists when assimilation and disassimilation are of equal value; it is disturbed by outside stimuli or irritants, because most of these do not affect assimilation and disassimilation alike.

It is one of the most important provisions in living things that, after an irritant ceases to act, the tissues return to the state of equilibrium, owing to the internal auto-reconstructive tendencies of a living organism.

If, for instance, a certain irritant or stimulus, as exercise, had acted upon dissimilation, upon the destructive phase of tissue-metamorphosis, in a living substance, the assimilative phase would under normal conditions become secondarily engaged in making good the loss occasioned by the stimulus acting upon the dissimilative phase in the process. When, however, an irritant or stimulus, with an effect upon dissimilation alone or almost alone, has continued to act for a certain length of time, there is finally brought about a condition in the living substance, due to an accumulation of waste-products, and this condition is known in physiology as *fatigue*. — The essential characters by which this condition is recognized, are: lowered excitability and a decrease in the amount of work done in a given time by the particular organ or tissue concerned. A careful study of this condition in its relation to training and education is of the utmost importance.

Let us, therefore, try to give it a place in our scheme and so help to fix its relation to our work in our minds. We know that absolute inactivity of any organ or tissue is followed by a process known as degeneration, and that activity, carried beyond the normal range of the endurance of an organ, is followed by exhaustion and paralysis. Between these two extreme limits lies the normal range, and somewhere within it we must find the optimum point of activity corresponding, at the same time, to the maximum capacity for work and which has the most favorable reflex influence upon the normal growth of any organ concerned.

Both degeneration and exhaustion border on the domain of pathology and are, therefore, rarely subjected to investigation on the part of the physiologist. But shortly before

we reach the point of exhaustion, on the downward arm of our binomial curve, we arrive at a point where we meet with a condition known as fatigue, and this being still considered within the physiological range, has been formally studied and investigated by some of our best physiologists. — As teachers, as educators, as the professed promoters of normal growth and development in human beings, entrusted to our care by a confiding public, our first duty must be to do no harm under any circumstances. Our next duty is to influence for good the education of our charges. In order to discharge our full duty in this regard we must know (1) the danger points and signals, and (2) also the point or the conditions under which our work has its maximum beneficial effect. An acquaintance with that point within the physiological range at which the activity of any organ or tissue which we wish to place under the more favorable condition for development produces its optimum beneficial effect, is a necessary preliminary to success on the part of all educators. This point must lie about midway between the two danger signals, namely: absolute inactivity followed by degeneration, and exhaustion followed by paralysis from over-exertion. It must, moreover, lie at a point before fatigue occurs, for we have already seen that fatigue precedes the condition known as exhaustion and is itself due to the accumulation of the products of wear and tear, hence no longer presenting the most favorable conditions for growth and development.

I know of no instrument that has served to give us more real information as regards the normal or physiological range of functional activity than has the ergograph, simple as it is. The ergograph, at present, appears in two forms. In the case of the original instrument of Mosso, a muscle contracts against the resistance of a constant weight, while with the spring ergograph, employed by Binet, Catell, Franz, Hough, and Schenck, the resistance is variable, and allows the contracting muscle of a certain degree of choice or selection. The muscle, here, lifts what it can and no more.

Physiologically considered, the curves produced by Mosso's original instrument and by the spring ergograph respectively

have a significance of far greater difference than would at first sight appear. From a merely mechanical point of view, and somewhat roughly speaking, the difference between the two instruments is practically the same as that between the Sargent chest-weight on the one hand and the Whitely exerciser on the other. If we examine the curves produced by either the ergograph of Mosso and the spring ergograph respectively, and apply to them a certain arbitrary test represented by the formula $\frac{P.}{R.\ r.}$, where P. is the power of the neuro-muscular mechanism, R. stands for the resistance offered by the weight, and r. for the rate with which the weight is lifted, we find the difference to be as follows: The above fraction in Mosso's curves is, at first, for a short period equal to one and then rapidly loses, becoming less than one, and, finally, ends at zero for a numerator. In the curves obtained by the spring ergograph, our fraction begins by being at first slightly greater than one, and then slowly reaches a point at which it remains equal to one throughout.

Recent experiments by Verworn on fatigue, both with the ergograph on man and on the frog, with the usual recording instruments, have shown that both in muscle as well as in the central nervous system, excessive activity is followed by fatigue and exhaustion. Fatigue is that condition which is due to the accumulation of the products of wear and tear, and of which CO_2 is undoubtedly one; and exhaustion, on the other hand, is due to the lack of material necessary for the building up of the lost substances, and of which oxygen is at least one. Exercise of an organ stimulates the destructive phase, rest the assimilative phase.

Whenever the dissimilative phase is greater than the assimilative phase, which is the case in excessive exercise, the products of wear and tear accumulate in the tissue, and a decrease in the work done is bound to follow, for this constitutes the condition known as fatigue. Whenever the dissimilative stimulus is exactly counterbalanced by the assimilative phase, it is a sure sign that the neuro-muscular mechanism has reached its maximum point of efficiency and is doing as much as it is capable of doing, but is *not yet fatigued.*

In the curve obtained by the spring ergograph, it would appear that these two phases exactly balance one another, and thus a condition of tissue equilibrium is steadily maintained. The curve, therefore, is not strictly speaking a fatigue curve, but rather a maximum-efficiency curve. In the Mosso curve we meet with a steady increase in the dissimilative phase until the amount of fatigue thus produced prevents the lifting of a given weight, although the neuro-muscular mechanism is still able to lift a smaller one. Applied to our fraction, we find that P. becomes smaller with every new contraction as long as R. r. remain the same, as they must under the condition of this instrument. With the spring ergographic curve, the sensori-motor reflex arc, after a short time, picks out such a level which shall exactly correspond to a condition of tissue equilibrium or of its working capacity, without detriment to the tissues involved. It might then be used as a means of ascertaining the working capacity of any organ to which this instrument can be applied, and to give at the same time the degree of training which it has received or is capable of receiving from time to time and under a given number of different circumstances and conditions.

The curve, therefore, must be looked upon as of the highest importance in our work. Since we know that prolonged muscular- as well as brain-work is followed by practically the same results, and that the fatigue and the exhaustion in both are due practically to the same causes, the principle and the accurate appreciation of the same underlie all educational efforts, mental as well as physical. We have the best of reasons for assuming that the activity of any organ, whether brain or muscle, when kept within its normal range of physiological endurance, excites or stimulates the growth and development of that organ by stimulating alike both the dissimilative and the assimilative phases; when carried beyond the normal range, or even the point of fatigue, it has the contrary effect.

Growth means that the supply of energy which follows a demand upon it must be greater than that amount which was demanded, for it is in this manner alone that exercise can be

followed by an increase in working capacity. The same physiological process then underlies all successful training. All training and education have their physical basis in a living organism, although every organ in it has evolved, within its own substance, its own peculiar specific energies, and the same stimulus produces reactions that differ with the particular organ upon which it acts.

But the reflex arc, through which we are trying to develop, train, and educate different parts of our anatomy, consists in all essentially of the same elementary parts, namely: (1) A peripheral sense-organ (in which we would include the tactile-, pain-, and temperature-sense in the skin); (2) an afferent nerve; (3) a sensory centre in the spinal chord; (4) an association of centres in the brain, producing conscious impressions; (5) a motor centre in the spinal chord; (6) an efferent nerve; and (7) a neuro-muscular end-organ. All these various structures are capable of being developed and trained; brought to a higher degree of efficiency, when acted upon under favorable conditions, and well within the normal physiological range of their capacity; they are liable to become fatigued and exhausted under the contrary conditions; they may also undergo repair and restitution by rest and sleep, owing to the auto-reconstructive tendencies peculiar to all living things. — For the physiologist, then, it makes no essential difference whether you train a child in the mastery of the three R's, or whether you teach it to play a musical instrument, to run or to jump, the process in its essential and elementary parts is physiologically the same in all. And, as long as the training requires the man to be in the state of consciousness, the brain, this great central power-house of his entire machinery, must always receive the attention in keeping with its importance. — Thus, training in which muscular contractions form a prominent part, in the physiological sense, is no more exclusively physical than the training of a child in the art of writing or reading is exclusively mental. In all a certain reflex sensori-motor arc, with the brain as the centre of consciousness, is engaged in doing a certain amount of work, intended for the increase of its

working capacity, and the special education of a certain part of our anatomy would simply mean that our purpose was to raise the specific energy in that particular part to a higher degree of efficiency than it could be expected to reach without such education. — Physical training has entered the scientific stage in its development, and has long since ceased to look upon the mere increase in size and strength of muscle as the highest of its aims. In training for grace and manual dexterity, for instance, the mere increase in the size of muscle may even be looked upon as a most undesirable by-product. An enlargement of the tongue would certainly not constitute the highest nor the most desirable attribute of an orator. In a most general sense, our aims are to bring about a proper and symmetrical adjustment between all the parts of our anatomy, so that, in the words of Huxley, the body becomes the ready servant of the will, and "does with ease and pleasure all the work that, as a mechanism, it is capable of," and together with the intellect forms "a clear, cold logic engine with all its parts of equal strength and in smooth working order."

Having dwelled briefly on the physiology of the training of the body as a whole, which practically implies an attempt of making one part of the body as good as every other part, we must now look for a moment at the physiology involved in some of the results that have been obtained by the training of special parts of our anatomy, and the relation and indirect influence which such parts bear to the rest of the body. In connection with this subject we are, in the first place, reminded of the work of Scripture, published about a year ago, on what he called "Cross-education." The physiological principle which is involved in the results obtained by Scripture's simple experiments seems to me of an importance so far-reaching and fundamental from the point of view of training, that it should have been followed up with greater interest. Scripture's results would show that the exercise of one arm is followed by an increase in the strength and circumference not only of the arm thus exercised, but also of the one on the opposite side, and not doing any exercise. The measurements on that occasion were made by Dr.

Seaver, and we, therefore, must conclude that they were taken with sufficient care to insure us their accuracy and correctness.

Here, then, we would have an instance in which the special training of one part of our anatomy is seen to have an indirect influence upon remote parts. Such results as these would appear to support the idea that the exercise of our muscles might, indirectly, favor the performance of intellectual work. That this necessarily must have its normal limits we can assume with perfect certainty; but what these limits are we as yet have made little progress towards finding out. All we do know so far is that there exists a functional or physiological correlation between the different parts, as well as an anatomical one, and that, in training special parts, an overflow, as it were, occurs that affects parts remote from the one under special training.

Considerable interest has been devoted within the last two years to the subject of the relation existing between physique and mental ability. The observations of Porter, Hastings, Christopher, and myself would point to the fact that there is an undoubtedly direct relationship between the two. In a paper which has not yet been published, from the measurements of some three thousand children in Cambridge, this direct relationship is again beautifully shown to exist.

Quite recently my attention was called to an article by W. C. Bagley, " On the Correlation of Mental and Motor Ability." Bagley, from his experiments, finds an inverse relation to exist between motor and mental ability. He, moreover, finds little direct relation to exist between mental ability as represented by reaction times, and mental ability as represented by class standing, except that excellence in either is apt to be accompanied by a deficiency in motor ability. The results of Bagley are very interesting indeed, but have only a remote bearing on the subject treating of the relation between *physique* and mental work; and I should not have mentioned them in this connection had they not misled one of my friends into thinking they were contrary to those obtained by others and myself.

In so far, for instance, as Bagley's data from "experimental sources" are concerned, we will find that the tests which he made for strength, rapidity of voluntary movement, control or steadiness of motor co-ordination, etc., are all tests, combined with certain mental processes, requiring for their execution considerable training if expected to be done well. Our conclusions, on the other hand, are merely based upon physique pure and simple, as determined by a few crude anatomical measurements in a limited number of dimensions, and its relation to the mental work done by children, as the result of the training that they received in their schools. Physique, in my opinion, cannot be made to stand for motor ability. Ability is the normal function of physique, and implies a certain amount of training which is not implied necessarily in the term "physique" as determined by measurements. We may, therefore, assume provisionally, at any rate, that there exists a direct causal relationship between physique as determined by certain measurements, and mental ability as determined ordinarily in schools; for a high percentile rank, as regards physique, is almost invariably found associated with a high grade of mental work in growing children. Knowing, moreover, that muscular exercise, when administered under the most favorable physiological conditions, is followed and accompanied by an increase in growth of the height, weight, chest circumference, and muscular strength, over and above that amount which occurs without such exercise, physical training would seem to stand upon fairly solid and scientific foundations; for we now can scarcely escape the temptation of making the further deduction from the above two propositions, that whatever gives rise to increased growth in height, weight, and chest circumference must also indirectly lead to increased brain development; and, *vice versa*, whatever impairs the normal physical growth must also indirectly impair mental growth.

It is generally held that brain work has an unfavorable influence upon the growth of the body, and one of the great claims of physical trainers is that bodily exercise is necessary in order to prevent the physique of our children from break-

ing down, while their brains are being trained and educated in the schools. Undoubtedly there must be some good and cogent reasons for this general belief, but have we anything of a more scientific nature than that for our assumption? So far at least I have been unable to find anything in literature with regard to this point.

Arguing merely from analogy, it would seem rather paradoxical to a consistent physiologist to find while muscular exercise favorably influences brain development that brain exercise or work should have an unfavorable influence upon the growth of the body.

While thinking about this subject it occurred to me that one of the means of approaching the problem with a chance of getting some light on it would be to compare the growth curve between boys who went through the high school and into college and those who did not, beginning after both left the grammar school; at the same time selecting a class of boys in whom no other essential differences as regards environment and other hygienic conditions exist — in other words, boys in whom the superior mental training which they get in the higher schools can be said to constitute the chief if not the only difference influencing their lives and growth.

An approach to such a condition may be found in the difference in the training of naval cadets on the one hand and naval apprentices on the other. Both classes of boys start about the same age; their work on board ship as well as their drills on shore are almost identical; the food which they get has about the same value in calories, the difference being that the cadets are served better than the apprentices; both get at least eight hours' sleep; the cadets do about the same amount of work with their hands as do the apprentices; in fact, we have here the rather rare opportunity of comparing conditions of life in which the superior mental training received by the cadets at the naval academy may be said to constitute the chief if not the only difference. Consequently their respective growth curves when compared to one another ought to give some very valuable information with regard to this point.

The necessary material for such curves was found, partly in the growth tables published by me in 1895, partly in the tables not yet published, and compiled from the physical examination records of a large number of naval apprentices and landsmen for training.

Mean Values, derived from 4,541 Cadets and 3,445 Men and Boys, Compared.

Age.	Height (In.)		Weight (Lbs.)		Chest Circm. (In.)	
	Cadets.	Men.	Cadets.	Men.	Cadets.	Men.
15	64.29	63.37	108.50	109.00	29.95	30.07
16	65.80	64.01	116.90	114.42	31.10	30.40
17	67.00	64.87	124.80	122.60	31.89	31.34
18	67.63	65.43	131.80	124.94	32.68	31.80
19	67.65	65.68	137.00	128.45	33.25	32.00
20	68.25	65.84	138.50	133.90	33.58	32.50
21	68.21	66.10	138.90	134.90	33.65	33.14
22	68.35	66.31	138.70	140.08	33.77	33.62
23	68.52	66.45	138.30	140.85	33.87	34.00

The adjoining table is intended to exhibit the differences in the mean height, weight, and chest circumference between the two classes of boys. On examining the several columns of this table, we will notice, so far as weight and chest circumference are concerned, the apprentices have a slight advantage over the cadets, beginning with a slightly higher mean in both these dimensions. As regards height, on the contrary, the cadets have a more decided advantage over the boys, having the start of the boys to the extent of a little less than one inch.

From that time on, however, the cadets rapidly gain over the apprentices and forge ahead of them in all three dimensions, up to the eighteenth and nineteenth year; the cadets

continue to keep ahead in height up to the twenty-third year, which marks practically the end of growth in height, but allowing the men to pass them in both weight and chest circumference just about the same period. The difference in the mean height between cadets and men at the twenty-third year is two inches. These conditions may be seen more strikingly represented in the three charts adjoining p. 446, this journal. This looks as if brain work might influence favorably bodily development, at least under the conditions here referred to.

The average human life in the 17th century, and, counting out the devastations caused by epidemics such as the plague, etc., was from eighteen to twenty-two years. Recent statistics have shown that this average has increased to forty and forty-five years, so that we have good reasons for supposing that a normal life, under the most favorable conditions of heredity and environment, ought to last ninety instead of seventy years. Let us try to realize and locate our relation to such a life in our capacity as teachers, trainers, or educators.

We can do this best, I think, by constructing an arbitrary binomial curve, representing the beginning, the rise, decline, and end of a normal life of ninety years' duration (see fig. 1).

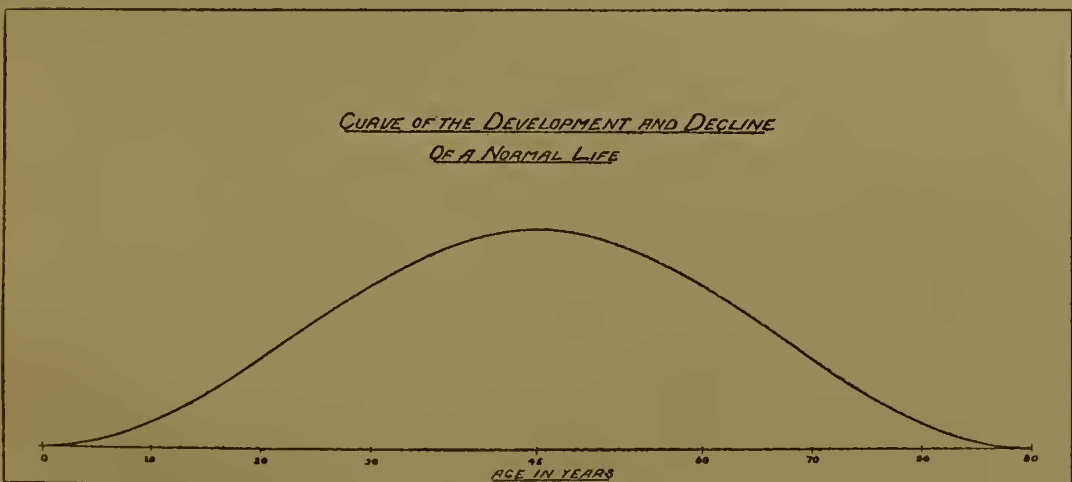

FIG. 1.

Dividing, to begin with, this curve into three great periods of thirty years each, we will note at once that the weight of our influence for either good or evil, as the case may be, falls

heavily into the middle of the first of these three periods, namely, that included between the tenth and twentieth years of life, tapering off at either end into early childhood on the one hand, and early manhood on the other. The second period, that which is included between thirty and sixty, or the middle period of life, as it might be called, is the one during which man performs his best work. It is the auto-creative period of life. The amount and quality of his work will greatly depend on how he was reared, taught, and educated, and in the free competition of life it will largely determine the rank and station which a man will attain among his fellow men, amounting in fact to an examination into his real and all around worth and value of thirty years' duration, and of an intensely practical character. While, during the third period of life, that included between sixty and ninety, a man must reap what he has sown, as it were, during both the previous periods. Here nature is very apt to prove to man, in the form of a final reckoning, that a painless decline of his years and a normal death from old age can only be the reward of a correct and useful life.

Having now localized our relation as educators to a single life, we have still much to learn by looking at the mortality curve of a whole nation. It will remind us more especially of the scope of our tasks still before us; of work yet undone or wrongly done. According to Carl Pearson, 605 out of every 1000 of children conceived, die before they are born; very many die in childhood; fewer in youth, more again in middle age, and many more still in old age. The mortality in infancy is indeed so great, that even a small reduction in the number of deaths of infants would be a readier means of checking the decline in population of some countries than would any other plan for fostering a higher birth rate.

From a statistical study of the mortality rate, Carl Pearson has made five ages of man, viz.: Infancy, childhood, youth, maturity, and senility. He has expressed his conceptions graphically in an extremely thoughtful and interesting manner. His picture shows the causeway of life in the form of a bridge on which each age is represented as passing, with

the marksman Death, hovering about and armed with different weapons of precision, killing as the men pass. The idea of the large number of ante-natal deaths is represented by man killing his own offspring with his own bones; next, during infancy, a maxim gun sweeps down the living; then, in youth, a bow and arrow is seen in the hands of the marksman; than an old blunderbuss comes; at last, a modern rifle is necessary to pick out each man because the ranks have become so thin.

Enough has been said, I think, of the value of anthropometrical records as well as statistics in general and their bearing upon the physiology of education. It was, moreover, clearly pointed out that all efforts at education, whether general or special, involve the training by exercise of a portion of the anatomy of the person to be educated; that such exercise, to have the educational value it is intended to have, must be kept well within the limits of the normal physiological range of the endurance and capacity of the parts involved. For purposes of orientation and for the study of the effects and defects of our work, of the flaws in our methods and products, and the problems to be solved in the future, we will find there is much to be learned by a consultation of our mortality statistics.

Boston Society of Medical Sciences, May 7, 1901.